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An experimental digital television recorder

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AN EXPERIMENTAL DIGITAL TELEVISION RECORDER

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Summary

This report describes the development of an experimental digital television recorder. It uses a sub-Nyquist sampling system at twice colour sub-carrier frequency.

An outline of the method of operation of the machine is given with particular reference to means whereby errors caused by tape drop-outs may be concealed or corrected.

The performance of the machine is described and suggestions are made as to possible uses for the machine as a research tool within the Department.

Issued under the authority of

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Introduction

Research Department's work on digital magnetic recording to date has been principally directed to the production of an experimental digital television recorder. To this end, a start was made by building a digital sound recorder in order to study, with rather less stringent requirements, the problems involved. This work has already been fully described in a Report.[1] The television recorder uses the same principles of design as the sound recorder, and the present Report will be confined, in the main, to the points upon which they differ.

1. Parameters of the digital television signal and of the recording system employed

1.1. The signal

Some of the characteristics of a p.c.m. coded PAL colour signal have already been well established. A sampling rate in excess of twice the analogue bandwidth of the signal has, until fairly recently, been considered necessary and, for various reasons, it is convenient if the sampling rate is a multiple of the colour subcarrier frequency. Thus three times this frequency is suitable, giving a sampling rate of 13·30085625 MHz. However, at about the time that the present recorder was under development, a means of sampling a PAL encoded television signal at the sub-Nyquist rate of twice colour subcarrier frequency (8·8672375 MHz) was successfully developed.[2]

The other important parameter is the number of bits required to describe the amplitude of each sample. Eight bits per word provide 256 different quantum levels per sample, and tests have shown that this number is satisfactory for broadcast purposes.

The design of the recorder is such that with the lower sampling rate, a data rate of about 1·8 Mbit/sec is handled on each track; it is hoped that future developments may permit operation at the full rate.

It was an important principle in the design of the machine that none of its circuits apart from those involved in error concealment should rely on the fact that the data recorded was derived from a television signal.

1.2. The magnetic recorder

Experience with the sound recorder led to the conclusion that the best recording technique to use in an experimental approach to digital television recording would be a longitudinal one; that is to say, a format comprising many tracks running along the tape, the heads being stationary. Heads are available providing 42 such tracks on one-inch tape, and which are capable, in an analogue application, of operating at 2 MHz per track at a tape speed of

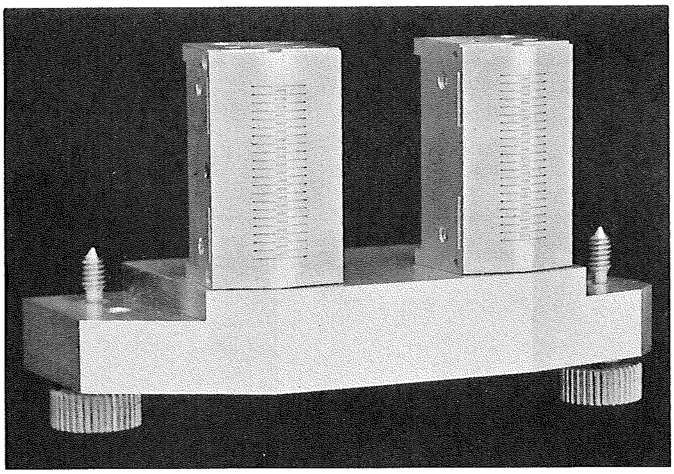


Fig. 1 - 42-track headstacks

120 inches per second. Fig. 1 shows the two recording headstacks that together lay down 42 tracks; the replay heads are similar.

An experimental set of such heads was tested with a view to using them for digital recording. A square-wave response/frequency characteristic[1] was measured and data recording tests using pseudo-random sequences were carried out. Signal to noise ratio measurements were also made.

1.2.1. Frequency response

The square-wave frequency response is shown in Fig. 2. This type of response is measured by driving the record head with constant-amplitude square-wave current, and measuring the peak-to-peak voltage obtained from the replay head, irrespective of its waveform.

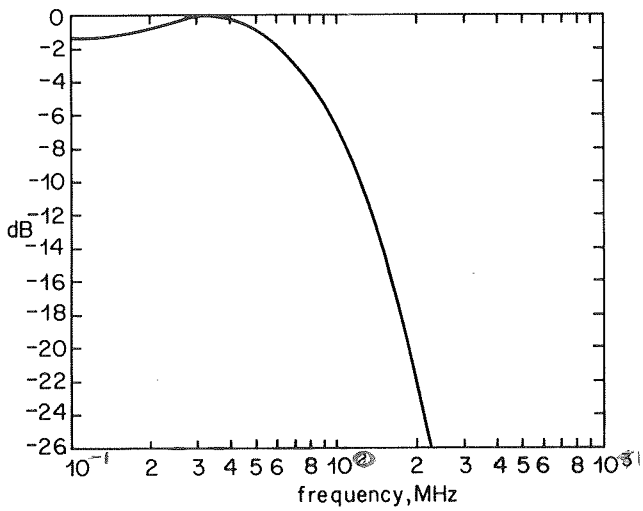


Fig. 2 - Square-wave frequency response of single track system at 120 i.p.s.

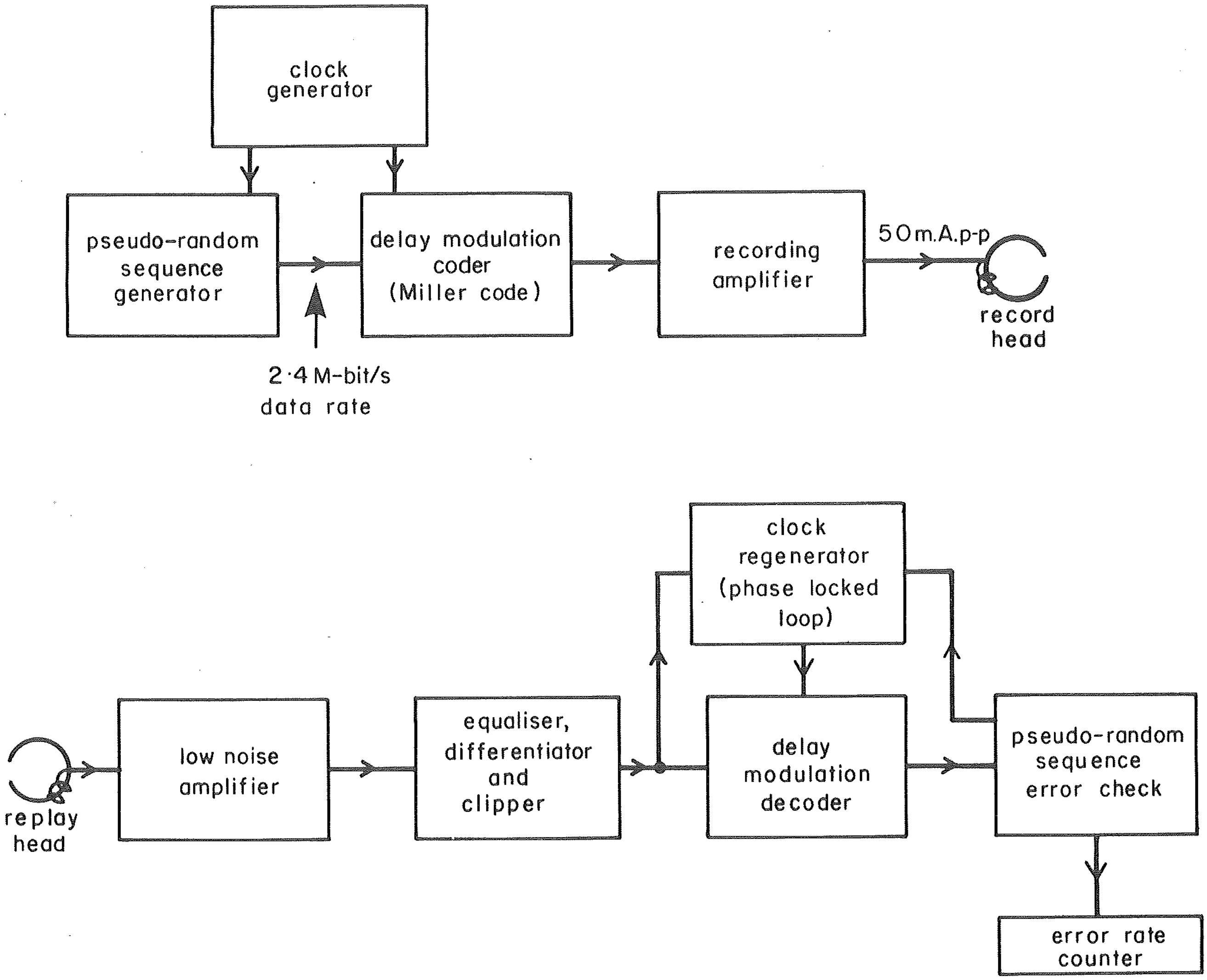


Fig. 3 - Block diagram of equipment used to measure the achievable packing density

The response at 2·4 Mbits/sec is about 26 dB below maximum on this graph; it was considered that, with the use of appropriate equalisation and phase-locked-loop clock regeneration, data at this rate should be recoverable.

1.2.2. Signal-noise ratio

The noise, (relative to the peak-to-peak magnitude of a replayed 2·4 Mbit/sec pseudo-random sequence), was measured in quasi peak-to-peak terms on an oscilloscope. The figure for signal-to-noise ratio in these terms was 34 dB, which is adequate for signal recovery.

1.2.3. Data recording tests

The heads were mounted on the same type of transport as was to be used for the recorder. The maximum data rate achieved was 2·4 Mbit/sec using delay modulation, no r.f. bias, a tape speed of 120″/sec, and high-energy video-tape (equivalent to Scotch 971): this represents a packing density of 20,000 bits/inch. The measured error rate was slightly less than 1 in 10^4, which is considered reasonably satisfactory. Fig. 3 shows a block diagram of the arrangement used for the measurements.

Thus all three measurements indicated that the heads should be suitable for use at a data rate of 2·4 Mbits/sec and this implied that 5 tracks could be used for each bit stream* of the television signal, and that 40 of them would be needed for all 8 bit streams.

In practice, however, although a single track operated satisfactorily at 2·4 Mbits/sec, this was too near the limit of head performance to permit multi-track working at such a high data rate; the unavoidable cross-talk between tracks prevented satisfactory data recovery. However, by means of the twice subcarrier sampling technique, the bit rate requirement per track was reduced to 1·8 Mbits/sec, i.e. within the practical working range.

* Assuming eight parallel bit streams, each carrying one bit of each digital word of the p.c.m. coded signal.

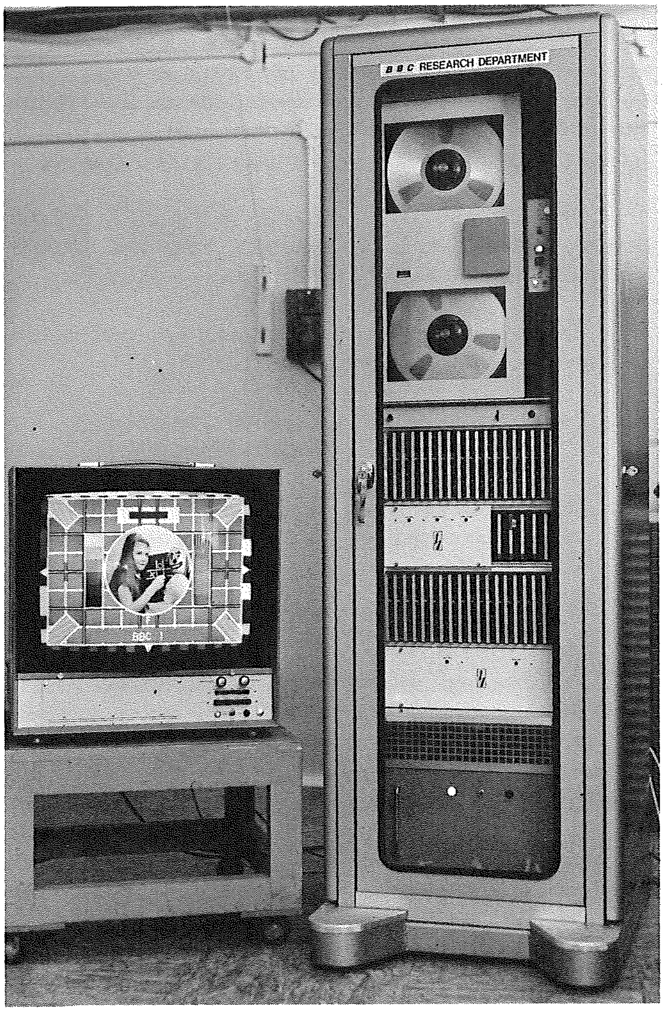


Fig. 4 - The replay of a test card by the experimental recorder

2. Recorder design

2.1. General

A photograph of the experimental recorder replaying a test picture is given in Fig. 4. The overall principle of operation is identical with that of the sound recorder.[1] Direct recording is used without the use of high-frequency bias; although the recording current is carefully controlled. A similar system of timing correction is incorporated, together with a tape-transport servo to control the tape speed and keep the timing corrector within range. The design of processing circuits, is broadly the same as used in the sound recorder but with some changes to accommodate the higher frequency of operation, and to incorporate improvements in the arrangements for framing-pattern detection.

In one respect, however, the design philosophy differs. In the sound recorder, each printed circuit board was restricted to a relatively simple function, and contained as many circuits for carrying out this function as there were tracks. In the television recorder, all processing functions associated with each track are combined on one board with the exception of the replay head amplifier, the record driver, and some housekeeping circuits. Thus all signal processing is carried out on 42 identical boards, one for each track. Multiplexing and de-multiplexing of the signal into and out of the processing boards is by means of bus bars and multi-phase clock pulses.

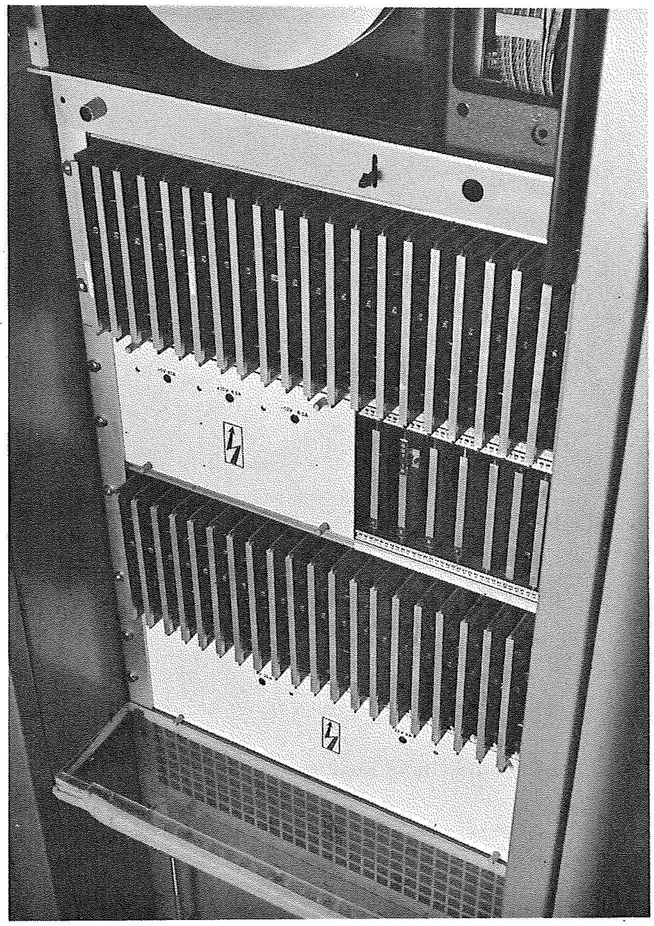


Fig. 5 - Location of digital processing circuits

Fig. 5 shows how the 42 processing boards are assembled in the machine in two 21-board racks. The intermediate rack contains control and error correction circuits.

2.2. Specification

Tape speed	120 inches/sec
Tape width	1 inch
Tape type	Scotch Type 461
No. of tracks	42
No. of tracks allocated to each bit stream	5
Recording time	Approx. 8 minutes on 10-inch reel
Transport	S.E. Laboratories T.D.10 Mk. II
Heads	Spin Physics
Recording code	Delay Modulation (Miller Code)

The information on each track is divided arbitrarily into 1024 bit blocks, for timing-correction purposes, and an 8-bit framing sequence is inserted between each block.

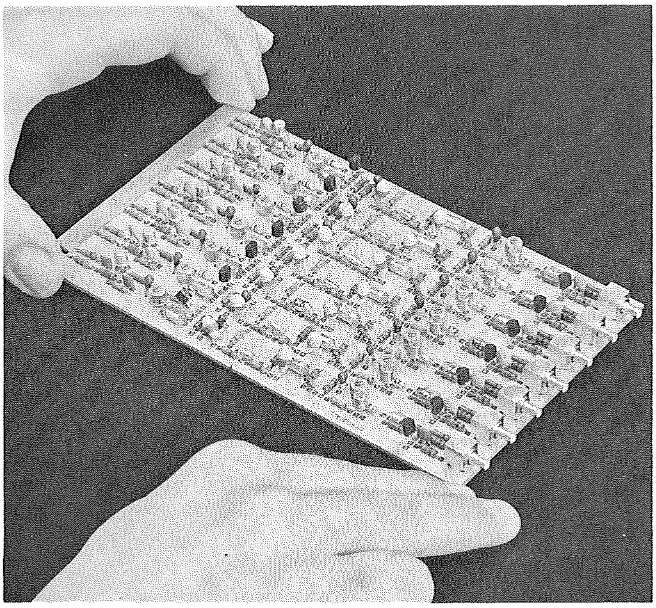


Fig. 6 - Replay amplifiers

2.3. Signal processing

2.3.1. Replay head amplifier

The head amplifier is designed to meet three main requirements: low input-capacitance, low noise, and low component-count. The input-capacitance must be low so that the resonant frequency of the heads is not brought down into the working frequency range. Low component-count and compactness are important as the recorder has 42 such amplifiers. Seven amplifiers are accommodated on each of six printed circuit boards as shown in Fig. 6.

The amplifier is split into two stages of about 35 dB and 45 dB gain respectively with a passive equaliser between the two sections. To achieve low input-capacitance the first section, which is separated from the head by about 18″, uses a guard ring technique, using a miniature tri-ax cable having two independent concentric screens. The inner screen is connected to a low-impedance point within the amplifier, and the voltage at this point is adjusted to follow that at the input. Fig. 7 shows the circuit details.

The first stage is also designed to provide the lowest possible noise figure. The input transistor was carefully chosen, taking into account the head source-impedance.

The performance of the head amplifier (without the passive equaliser) is as follows:

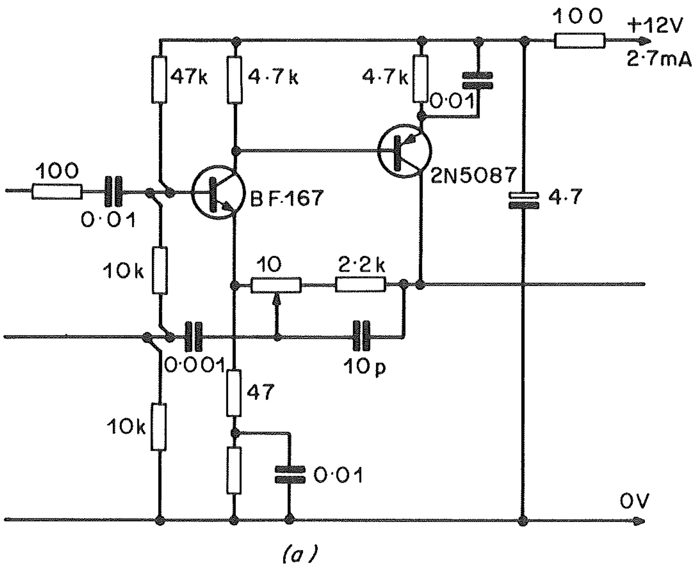
Bandwidth to −1 dB	550 kHz to 3 MHz
to −3 dB	350 kHz to 4 MHz
Gain:	79 dB mid-band
Max. output level:	4 V p-p
Input impedance with 20″ of cable:	22 KΩ in parallel with 5 pF
Noise figure:	2 dB with a source impedance of 1–2 KΩ.

The required equalisation provided by the passive network between the two halves of the replay amplifier consists, basically, of a differentiator, so that the peaks in the replayed waveform appear as zero crossings in the equalised signal. In practice some phase equalisation is also needed, and the amount required is difficult to predict accurately. Accordingly a variation of the single differentiator was derived by experiment; the circuit used is shown in Fig. 8 and the response/frequency and phase/frequency characteristics of the network are shown in Fig. 9.

The resulting waveforms are shown in Fig. 10.

2.3.2. The record head drivers

The record head drivers are extremely simple, being merely electronic switches, operated by the coded data



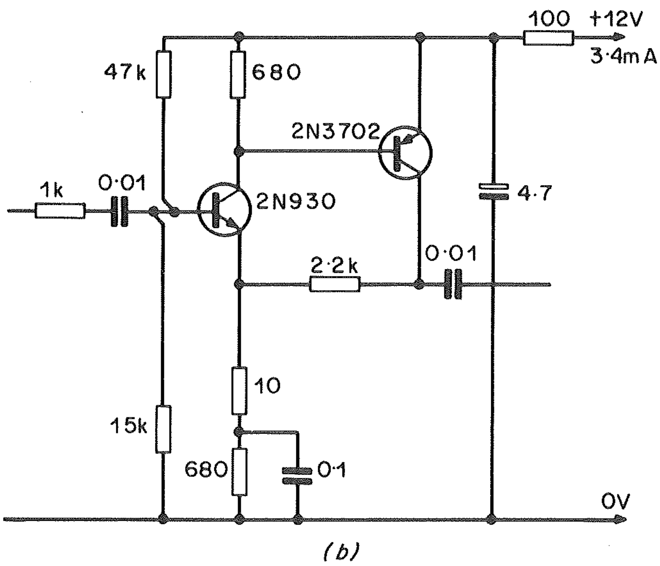


Fig. 7 - Circuit diagram of replay amplifier
(*a*) First stage (gain 35 dB) (*b*) Second stage (gain 45 dB)

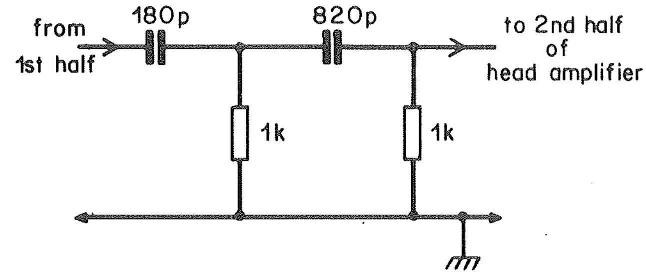


Fig. 8 - Differentiating circuit used in replay amplifier

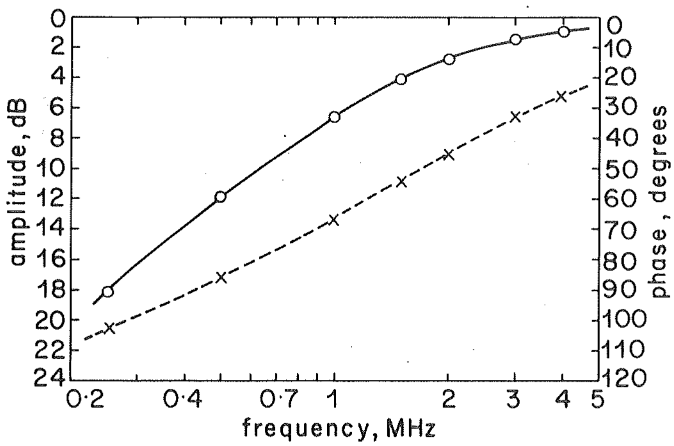


Fig. 9 - Phase and frequency response of differentiating circuit

0——0 Phase X— — —X Frequency

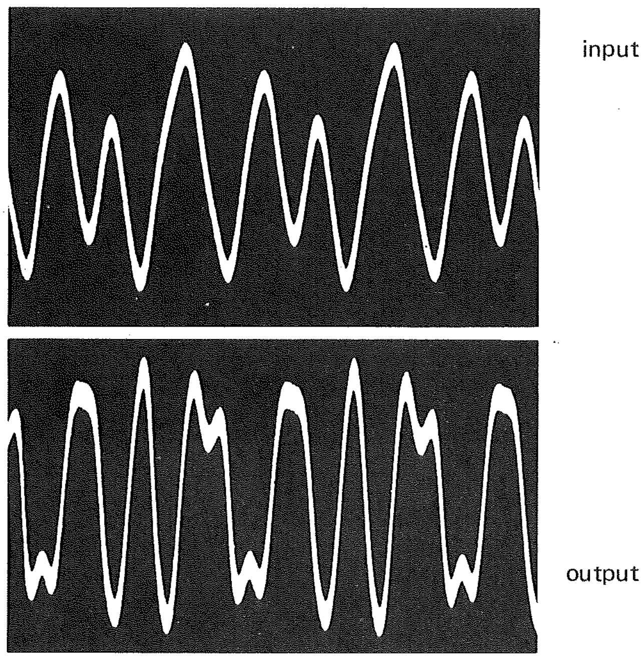


Fig. 10 - Input to and output from equaliser

stream. The heads are centre tapped, and are connected by these switches to a source of voltage via a limiting resistor. The recording current may be varied in all tracks simultaneously by varying this voltage source.

2.3.3. The main processing board

The main processing board accepts the data to be recorded on its associated track, splits it into blocks of 1024 bits, and inserts 8-bit framing patterns between the blocks. The resultant data stream is delay-modulation encoded,[1] and passed on to the record head drivers.

On replay, this same board accepts the data (after equalisation), slices it to make it TTL compatible, and regenerates suitable clock-pulses. Clock-pulses and data then enter the timing-correction circuits, where the data is re-clocked by station clock-pulses, thus removing timing errors. The framing pattern, having served its purpose is also removed.

All the above operations are similar to those in the sound recorder[1] and so need to be described no further here.

A photograph of one of the processing boards is given in Fig. 11.

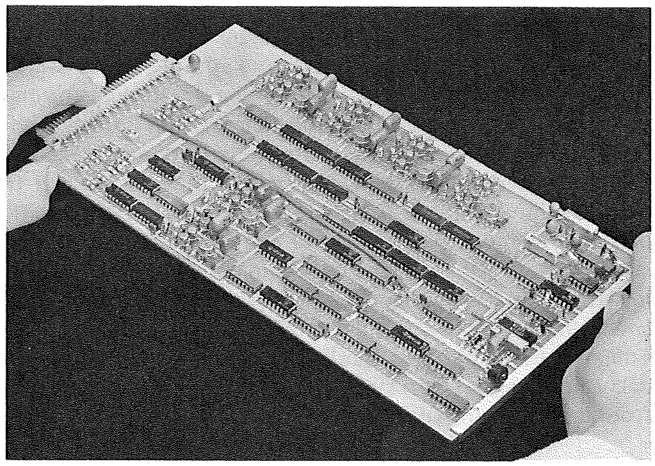


Fig. 11 - Processing board

3. Errors

3.1. Error performance

The average uncorrected error rate is about 1 in 10^5. Random isolated errors sometimes occur, but by far the majority of the errors are caused by tape drop-outs, which typically occupy 20 – 30 mils of track length, and affect up to 1000 bits at a time. During a drop-out a largely random sequence of data is produced* resulting in an average error-rate of 50% during the drop-out. Drop-outs seldom affect more than one track at a time.

With the coded television signal recorded on 40 of the 42 tracks, only two further tracks are available to implement any form of error concealment/correction system. Therefore each of these additional tracks can only carry

* The actual probability of I's and O's depends on the adjustment of the slicing level and the form of delay-modulation decoder employed.

one bit for each of five data words; this is clearly insufficient for a full parity protection scheme.

3.2. Error correction and concealment schemes

Several error correction/concealment schemes have been tried for use in the recorder. They are fully described elsewhere,[3] so a brief description only will be given here.

3.2.1. Concealment of most of the errors

It has been shown[4] that the impairment caused by data errors may be reduced if each erroneous data word is replaced by the average of valid words occurring before and after the erroneous one. For video signals sampled at twice colour subcarrier frequency, the mean of the second previous and second subsequent words may be used. As each bit stream in the sampled video signal is carried by 5 tracks of the recording, a drop-out on one track places only one word in five at risk. Thus a concealment scheme that is satisfactory for single word errors may be used to deal with drop-outs.

In order to describe this system, the tape may be regarded as being divided into five channels, such that each channel carries every fifth word of the recorded data. If an error burst occurs on one of the 15 tracks carrying the three most-significant bits it is necessary to know which of the 5 channels is in error. The two additional tracks are therefore used for parity bits that are allocated to the 5 channels in a cyclically changing way. When errors are present this results, on replay, in one of 5 different parity-check patterns, the pattern depending on which channel is in error. Thus, when the parity-check pattern is recognised, concealment can be applied. Some time is required to establish these patterns, and it is necessary to provide a delay in the signal path so that concealment may be applied from the beginning of the error burst.

This scheme effectively conceals about 90% of drop-outs affecting the three most-significant bits. The remaining 10% are somewhat visible (those occurring at transitions), and a very few escape detection altogether.

3.2.2. Simple parity

A simple parity system was also tested, in which the eighth bit of each data word was used for parity protection, the remaining seven carrying the video information.* This scheme will clearly detect odd numbers of errors in each word immediately, without the need to build up an error pattern over a period of time, as in the previous scheme. The parity indications were used to initiate concealment in the manner previously described.

This system worked rather better than the first, a greater proportion of the drop-outs being effectively concealed.

* This of course increases the quantising noise.

3.2.3. Correction of most errors and concealment of the remainder

The previous two parity schemes, whilst effecting a considerable improvement in the replayed picture, were nevertheless not considered satisfactory for a machine intended for copying through many 'generations' of re-recording. A system which permits some degree of error correction is potentially much more suitable for this application.

In order to apply error correction it is not only necessary to identify the work that is in error, but also which bit of that word. A combination of the two previous parity schemes may be used to achieve this end. The use of the eighth bit of each word for parity purposes indicates which word is in error, and the extra two tracks can be used, in a cyclic manner, to provide protection to the first four bits of each word. The latter establishes (as before), an error pattern that indicates which of these four bits is in error. (Note that in this scheme it is more convenient, and advantageous, to apply parity protection to the first four bits and not three as previously.) Where the errors are such that the two extra tracks give no clear indication of which bit is in error, the eighth bit provides sufficient information for concealment.

The improvement in picture quality obtained by introducing some measure of error correction is readily apparent, particularly with critical pictures. This facility is potentially of great value in the application where multi-generation recordings are made. The combined system was found to correct about 2/3 of all errors, concealing virtually all of the remainder.

4. Performance

The machine records and replays 8 minutes of high-quality television pictures. The only limitations on performance are the coding system involving twice-subcarrier sampling, the quantising noise resulting from the use of only seven bits per word, and the slight residual imperfections remaining after error correction/concealment. Timing errors are completely removed, and the picture is of course completely free from the noise, moire, head banding and patterning effects associated with conventional analogue VTRs.

5. Uses of the machine

Apart from the immediately obvious use of the machine to study the various problems inherent in digital recording in general, there are several other possible applications.

It is proposed to use the machine as a test bed for developing more sophisticated and powerful error-correcting and concealing schemes; it is considered that a digital recorder of this type will not be fully acceptable unless a very high proportion indeed of all errors can be corrected, and concealment only used as a last resort.

The machine will also be used to study the problems involved in multiple copying. This can be achieved by recording a tape with the transport running in reverse. On subsequent replay the record head is preceded by the replay head; thus the replayed signal after any necessary processing may be fed back into the machine and re-recorded a few inches further along the tape, erasure being carried out between the two heads. This process may be repeated as often as is desired, thus enabling multiple 'dubbing' to be correctly simulated using only one machine.

This latter facility will also be of value in assessing a number of digital processing techniques. If the processor is inserted in the signal path between the replay and record heads, the associated modification of the signal will be carried out each time that a new copy is made. Thus it is possible to assess the effects of carrying out such processing repeatedly.

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